Kennicott Glacier, Alaska: Ice Thickness Measurements using Ground Penetrating Radar (and Inexperienced Skiers)

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Abstract

What happens when you send a professor, a mentor, and seven inexperienced undergraduates into the field?

Dr. Erin Pettit and UAF graduate student Christina Carr led myself and six other undergraduates onto Kennicott Glacier in hopes of teaching us about glacier dynamics and glaciology field techniques. We spent seven days on the glacier. During this time we learned various cold-climate survival techniques and successfully collected ground penetrating radar (GPR) measurements to attain an idea of ice thickness.

Kennicott Glacier is located in the Wrangell Mountain Range in southcentral Alaska. It stretches 43 km from the top of Mt. Blackburn to its terminus in McCarthy, AK. Previous studies have used GPS velocities to estimate ice thickness. Estimated thicknesses range from 550m to 1080m using one model, and 400m to 820m using a second model . We used GPR to measure ice thickness and compared our thickness measurements to previous estimates. Our data show the ice thickness ranges from 300m to 600m. This is more similar to the second model's estimates, but around a 270m - 510m difference is present between the data.

Introduction

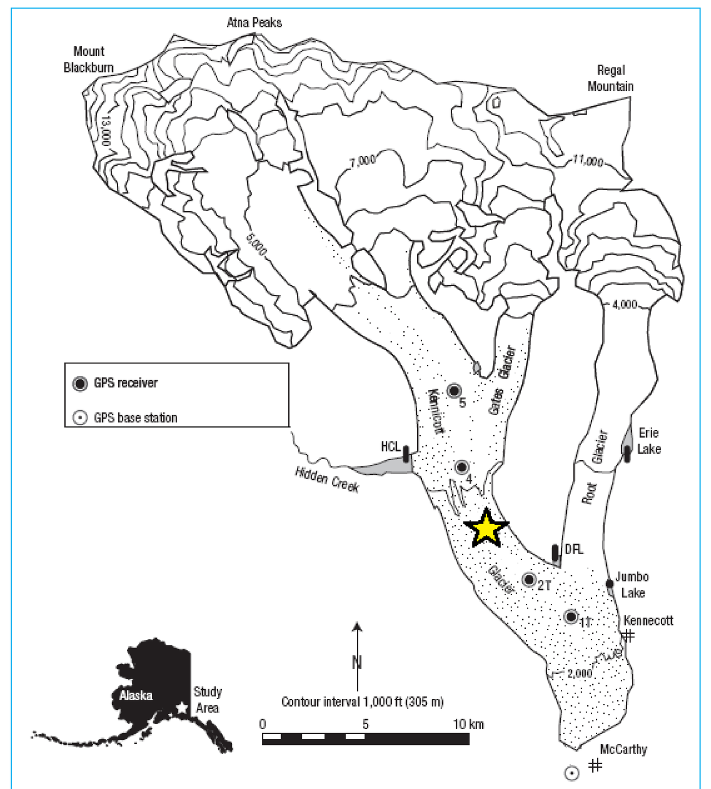

Figure 1. Map of Kennicott Glacier, Alaska. Black circles show GPS station locations. The white circle shows the GPS base station. The yellow star shows the location of our base camp at GPS station #3.

Figure modified from Bartholomaus et al., 2008

Five GPS units were installed on the glacier in the spring and early summer of 2011 by Bartholomaus et al. (Figure 1). The measured velocities from the GPS units allowed for ice thickness estimation.

The goal of this research was to use Ground Penetrating Radar (GPR) to measure the ice thickness and to compare the measured values with previous estimates. This research was part of a larger initiative by the University of Colorado at Boulder to model the subglacial hydrology of Kennicott Glacier and to understand basal sliding. It also served as an undergraduate field workshop to teach inexperienced undergraduates how to survive and collect useable data in the field.

Thickness Estimates

Thickness estimates were calculated using GPS velocities from five GPS stations on Kennicott Glacier.

Glacier thickness estimates were calculated using:

$$u_{\mathrm{def}} = \frac{2A}{N+1}(s_f \rho g \sin\alpha)^n H^{n+1}$$

- u_{def} — contribution of deformation to ice surface speed
- A — flow-law parameter $= 2.4 \times 10^{24}\ \mathrm{Pa^{-3}\ s^{-1}}$
- s_f — shape factor
- ρ — ice density $= 917\ \mathrm{kg\ m^{-3}}$
- α — ice surface slope
- n — Glen's flow-law exponent $= 3$
- H — glacier thickness

Two models were used for the contribution of deformation to ice surface speed:

1. 50% of steady motion at GPS receiver is due to viscous deformation, 50% due to steady basal motion
2. 100% of steady motion at GPS receiver is due to viscous deformation

Receiver	Distance from terminus* km	Elevation on day 186 m	Minimum horizontal speed $\mathrm{m\,d^{-1}}$	Surface slope, α $\mathrm{m\,m^{-1}}$	Glacier width m	Thickness estimate 1† m	Thickness estimate 2† m
GPS1	5.49	649.3	0.14	0.037	4420	550	400
GPS2	8.29	740.4	0.18	0.027	3290	860	680
GPS3	11.10	810.7	0.21	0.026	2960	1020	800
GPS4	15.04	917.2	0.29	0.027	3710	970	770
GPS5	18.58	1015.2	0.34	0.028	3420	1080	820

*Measured along glacier center line.

Table 1. Thickness estimates at each GPS station. Note the difference between models. The red box shows thickness estimates calculated from a model using 50% of motion due to viscous deformation and 50% due to steady basal motion. The orange box shows thickness estimates calculated from the model using 100% of motion due to viscous deformation. These estimates were created by Bartholomaus et al., 2011.

Methods

Ground Penetrating Radar (GPR) System:

- 2 Mhz Antenna at 80 meters
- 4 separate 20 meter sections composed of resistors at 1 meter intervals (Design by Tony Gades, University of Washington)
- Transmitter and receiver placed between sections (Figure 2)

Figure 2. GPR setup. The picture above shows the transmitter, pulled on a sled. The picture to the right shows Jessica Badgeley and Christina Carr troubleshooting the system.

Results

Figure 3. Plot of transects. Each transect is marked by dots of the same color. Larger colored lines correspond to the GPR images below. The large yellow star marks our base camp.

Following are GPR images from the transects highlighted in Figure 3, above. Locations along the transect are poorly constrained as the transect segments have yet to be aligned.

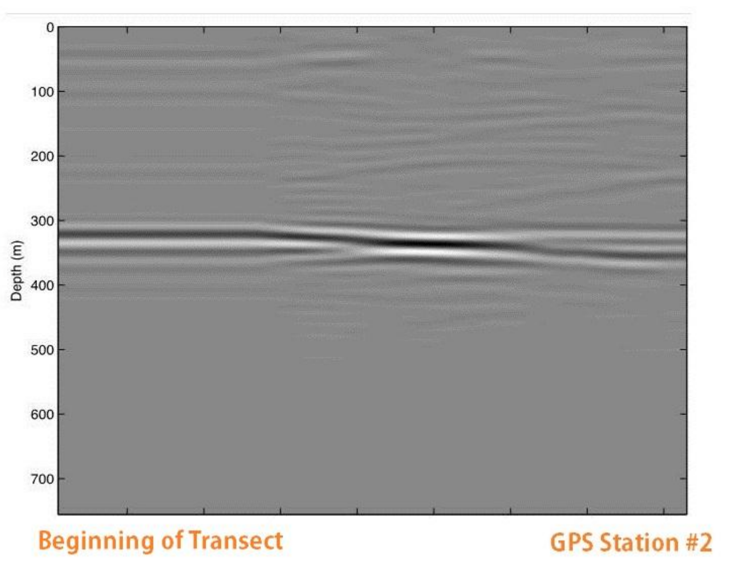

Figure 4. Image from the transect highlighted in light green in Figure 3. It runs to GPS station #2. The bed shows strong reflections at just over 300m depth.

Figure 5. Image from the transect highlighted in light pink in Figure 3. The bed shows strong reflections at about 500m - 600m depth.

Also note the hyperbolas present near the middle of the image.

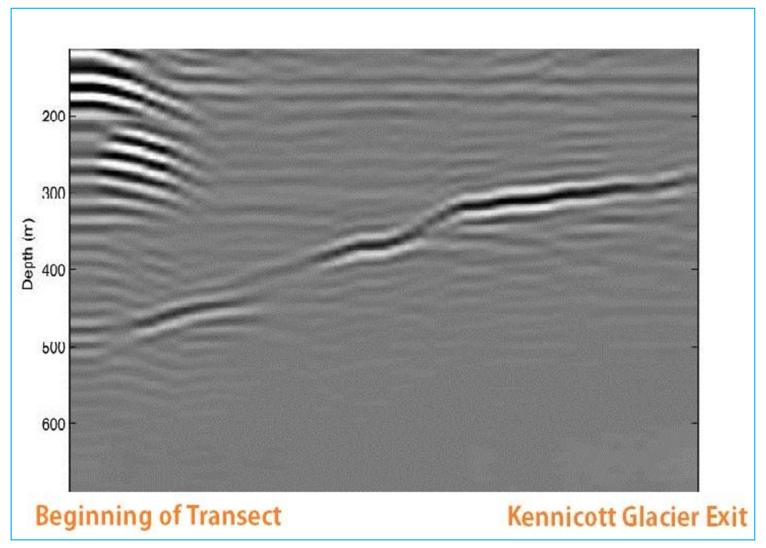

Figure 6. This transect covers a line near the trail exit on Kennicott Glacier. It is highlighted in fuchsia in Figure 3. The bed shows strong reflections between 300m – 500m. Note its parabolic shape toward the glacier's edge.

Conclusions

- Measured bed thicknesses range from 300m – 600m.
- Thickness estimates and GPR data at GPS location #2 differ by 330m – 510m.
- Thickness estimates and GPR data at GPS location #4 differ by 270m – 470m.
- Transects were separated into segments. Better constraints on transect locations will be made when segments are aligned.
- The hyperbolas in Figure 5 are most likely due to the presence of a moulin below the snow cover.
- The parabolic shape of the bed in Figure 6 shows that our location was relatively close to the centerline of the glacier. The centerline could be better constrained by making East to West transects across the glacier.
- Better GPR measurements may be obtained by revisiting Kennicott Glacier during the summer. The topography was difficult to ski across; crampons may offer a better form of transportation.

Acknowledgements

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References

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